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A RAPID METHOD FOR GETTING AREA-ELEVATION INFORMATION

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ABSTRACT: Area-elevation information can be collected with grid intersection sampling techniques more rapidly than by planimetering. A nomograph speeds the selection of grid spacing for 1) various sampling intensities, 2) drainage areas from 1 - 10,000 square miles, and 3) five standard topographic map scales. Routine calculations and linear interpolations within elevation classes are carried out by an IBM 1620 computer using a FORTRAN program.

Area-elevation curves have proved useful in evaluating a variety of meteorological and hydrologic conditions (Anderson 1958; Corps of Engineers 1956; Langbein 1947; Strahler 1952; Soil Conservation Service 1957). These uses range from temperature extrapolations to the determination of reservoir storage capacities. One author has even used such curves to study fluctuations in glacial regimen (Baussart 1961).

Planimetering and grid sampling are the two accepted data-collection methods for establishing area-elevation relationships. Planimetering the area between contour lines is the standard and most commonly used technique for Federal and private water resource construction agencies. It provides a complete survey of the watershed area but is slow and subject to human and instrument errors in the measurements.

In contrast, grid intersection sampling is faster and easier to apply than planimetering. Linsley, Kohler, and Paulhus (1949) state that it yields "equally satisfactory results" and that "In general, at

least 100 points should be used." Still the method has not gained much favor with hydrologists in the 30 years since it was proposed by Horton (1932). Perhaps skepticism about the accuracy of sampling explains this lack of acceptance.

Our preliminary tests have shown that area-elevation curves constructed by grid sampling will coincide with planimeter-determined curves, if enough sampling points are taken. Usually less than 500 points are needed with 8 elevation classes. As few as 100 points will yield highly useful information for most purposes. The two techniques are compared for the South Fork Eel River above Miranda, California (table 1). Grid sampling results are based upon 108 intersections. The maximum difference in percent area within a class was 3.57 (19 square miles). The difference between estimated mean basin elevations was 85 feet.

For many uses these differences would not be critical. For example, temperature extrapolations to the mean basin elevation would differ only 0.25 to 0.35°F., depending upon what lapse rate is assumed. If the limits of permissible error are more stringent, greater accuracy may be obtained by increasing the sampling intensity.

Table 1.--Area-elevation table, South Fork Eel River above Miranda, California--area, 537 square miles

Elevation class, feet	Percent area within elevation class		
	Grid	Planimeter	Difference
250-1,000	20.37	18.90	1.45
1,000-1,500	23.15	20.09	3.06
1,500-2,000	23.15	25.07	1.92
2,000-3,000	28.70	27.79	.91
3,000-4,491	4.63	8.20	3.57

Mean elevation:
Planimeter.........1,798 ft.
Grid...............1,713 ft.

In grid sampling, a uniform grid is laid over a topographic map(s) of the watershed. Considerable time can be expended determining the proper spacing of the grid lines for a given sampling intensity as this is a function of both drainage area and map scale. A nomograph (fig. 1) eliminates this bottleneck. To use the nomograph, enter with the drainage area of the watershed (A) and move vertically until the intersection with the sampling intensity line (N). Then move horizontally to the appropriate scale line (S) and vertically to the grid-spacing scale (I). For example, we have determined the grid spacing for the South Fork Eel River with 100 sampling points. The nomograph shows that the spacing should be 2.37 inches (scale I). This would be a cumbersome interval so every other line on a 1 inch grid was used.

Between 7 and 14 elevation classes are established on a watershed. The exact limits of each class are determined by the contour interval and the technician's judgment of the elevation distribution within the watershed. Ideally, about the same number of points should fall within each class. Colored pencils can be used to trace class boundaries to aid in distinguishing the different classes. Each grid intersection is then tallied within the appropriate elevation class.

All subsequent calculations are made on an IBM 1620 computer with a 20K memory. A FORTRAN program (fig. 5) for the computer is general for 7 to 14 elevation classes and for any type of relative area measurement (either sampled or planimetered).

Input for the program (figs. 2 and 3) consists of: (1) a watershed identification, (2) drainage area, (3) maximum basin elevation, (4) minimum elevation of each class, and (5) an integer value of relative area within each class. The watershed may be identified by any series of thirteen alphanumeric characters. For example, if the U.S. Geological Survey gage number is used, three digits will remain for dummy numbers or regional codes. The drainage area may range from .000001 to 99,999.99 square miles.

Output (fig. 4) includes: (1) class range, (2) class mean, (3) percent area in each class, (4) mean watershed elevation, and (5) an area-elevation table. The area-elevation table lists elevations by 0.1 increments of the original elevation classes, with the cumulative area in square miles, and cumulative percent area below that elevation. Linear interpolation within each class is used because it is the simplest model and there is no theoretical justification for any curvilinear function within a class. An output example is appended.

In practice we have usually required that the lowest and highest classes have at least one sample point. If no sample points fall within the highest or lowest class, we combine them with the next adjacent class. This procedure avoids nonsense statements in the table, such as "100.00 percent of the area is below 9,000 feet" when the highest basin elevation is actually 9,500 feet.

If a 1620 computer is available with a larger memory capacity than 20K, the program could be modified so that a larger number of elevation classes could be used. For most problems additional classes are not necessary. A second program modification would be warranted if a 1620 Auto-Plotter were available. This attachment could be programed to plot the tabular material of the area-evaluation calculations. In this case also, a larger memory unit would be necessary.

Literature Cited

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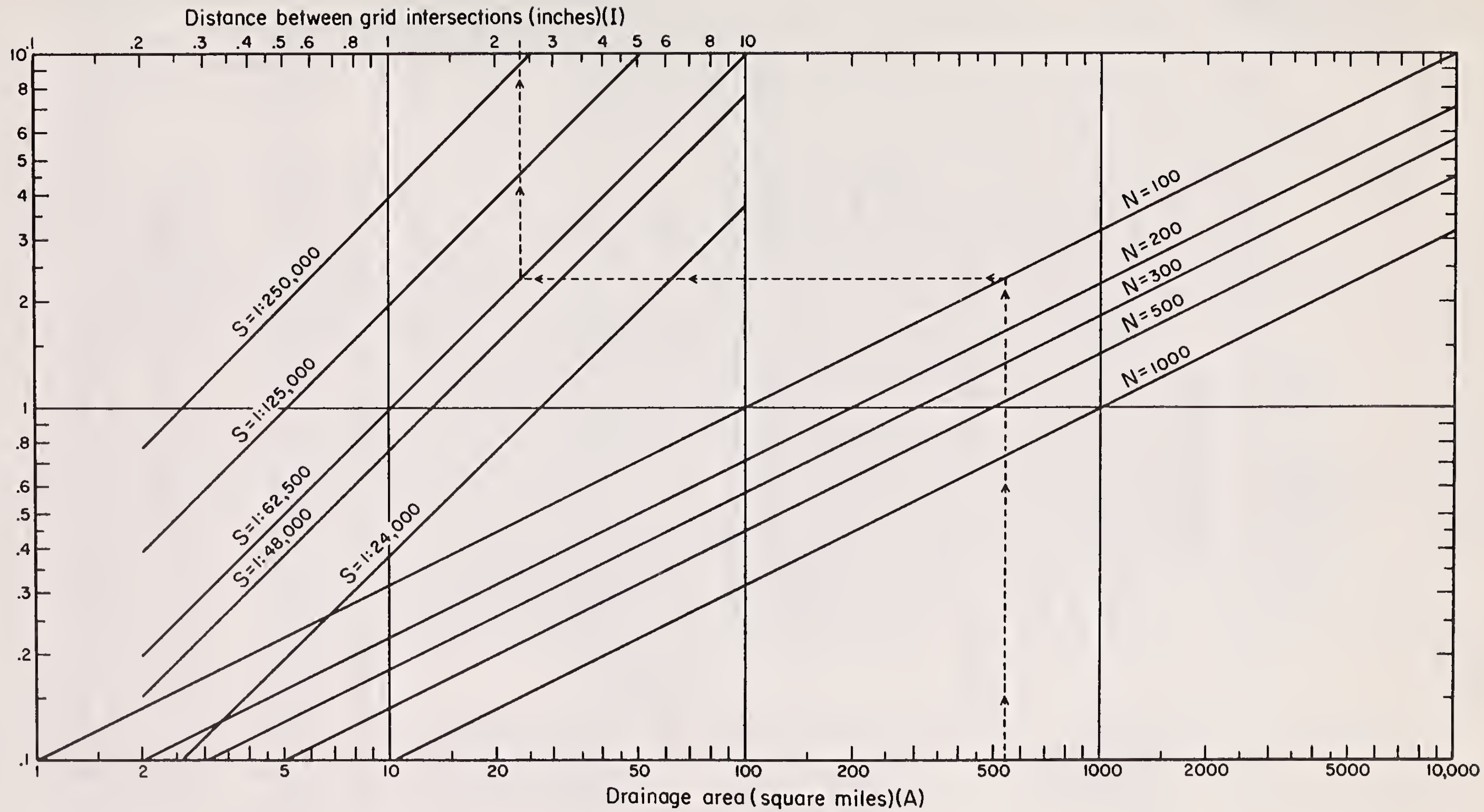

Figure 1.--Nomograph for determining grid spacing in inches from drainage area for various sampling intensities and map scales.

Figure 2.--Data input format.

Columns	Fields	Title
		Data Header Card
1-4	(I4)	Number of watersheds to be processed.
		Data Card One
4-16	(13H)	Alphanumeric watershed name.
17-29	(F13.6)	Watershed area in square miles.
32-37	(F6.0)	Maximum basin elevation.
43-44	(I2)	Number of elevation classes.
		Data Card Two (One per watershed)
19-23	(F5.0)	Minimum elevation of 1st class.
27-31	(F5.0)	Minimum elevation of 2nd class.
35-39	(F5.0)	Minimum elevation of 3rd class.
43-47	(F5.0)	Minimum elevation of 4th class.
51-55	(F5.0)	Minimum elevation of 5th class.
59-63	(F5.0)	Minimum elevation of 6th class.
67-71	(F5.0)	Minimum elevation of 7th class.
		Data Card Three (One per watershed)
19-23	(F5.0)	Relative area in 1st class.
27-31	(F5.0)	Relative area in 2nd class.
35-39	(F5.0)	Relative area in 3rd class.
43-47	(F5.0)	Relative area in 4th class.
51-55	(F5.0)	Relative area in 5th class.
59-63	(F5.0)	Relative area in 6th class.
67-71	(F5.0)	Relative area in 7th class.

<u>Data Card Four (One or none per watershed)</u>

Same format as Data Card Two but minimum elevations are for elevation classes 8 to 14. If less than 14 classes leave remaining fields blank.

<u>Data Card Five (One or none per watershed)</u>

Same format as Data Card Three but relative areas are for classes 8 to 14. If less than 14 classes are used leave the remaining fields blank.

Figure 3.

EXAMPLE OF AREA-ELEVATION DATA INPUT

9	HEADER CARD							
DATA CARD 1	F91220	12.5		2750	7			
DATA CARD 2		335	700	1000	1300	1600	1900	2200
DATA CARD 3		24	11	18	7	8	6	1
DATA CARD 1	F83100	105.		3209	8			
DATA CARD 2		50	400	800	1200	1600	2000	2400
DATA CARD 3		17	32	28	20	3	3	2
DATA CARD 4		2800						
DATA CARD 5		1						
	F91600	82.		4480	8			
		380	800	1300	1800	2300	2800	3300
		2	7	11	13	20	12	3

Figure 4.

EXAMPLE OF DATA OUTPUT FORMAT

WATERSHED NAME	AREA IN SQU MI	MEAN BASIN ELEV IN FEET	
F91220	12.500000	1085.	0

MIN CLASS ELEV	335.	700.	1000.	1300.	1600.	1900.	2200.
MAX CLASS ELEV	700.	1000.	1300.	1600.	1900.	2200.	2750.
MEAN CLASS ELEV	518.	850.	1150.	1450.	1750.	2050.	2475.
PERCENT OF AREA	32.00	14.67	24.00	9.33	10.67	8.00	1.33

CUMULATIVE AREA AND CUMULATIVE PERCENT
AREA BELOW LISTED ELEVATIONS

ELEVATION IN FEET	CUMULATIVE SQU MILES	CUMULATIVE PERCENT
371.	.40000	3.20
408.	.80000	6.40
444.	1.20000	9.60
⋮	⋮	⋮
2640.	12.46665	99.73
2695.	12.48332	99.86
2750.	12.49998	99.99

Figure 5.

FORTRAN SOURCE PROGRAM FOR 1620

```
 1 FORMAT (6X,34HWATERSHED    AREA IN    MEAN BASIN)
 2 FORMAT (9X,33HNAME        SQU MI    ELEV IN FEET)
 3 FORMAT (1X)
 5 FORMAT (16H MIN  CLASS ELEV7F8.0)
 6 FORMAT (16H MAX  CLASS ELEV7F8.0)
 7 FORMAT (16H MEAN CLASS ELEV7F8.0)
 9 FORMAT (16H PERCENT OF AREA7F8.2)
10 FORMAT (43H    CUMULATIVE AREA AND CUMULATIVE PERCENT )
11 FORMAT (34H      AREA BELOW LISTED ELEVATIONS)
12 FORMAT (43H    ELEVATION      CUMULATIVE    CUMULATIVE)
13 FORMAT (40H     IN FEET      SQU MILES      PERCENT)
14 FORMAT (6X,F7.0,5X,F12.5,4X,F6.1)
15 FORMAT (16H MIN  CLASS ELEV7F8.0)
16 FORMAT (16H MIN  CLASS ELEV6F8.0)
17 FORMAT (16H MIN  CLASS ELEV5F8.0)
18 FORMAT (16H MIN  CLASS ELEV4F8.0)
19 FORMAT (16H MIN  CLASS ELEV3F8.0)
20 FORMAT (16H MIN  CLASS ELEV2F8.0)
21 FORMAT (16H MIN  CLASS ELEVF8.0)
22 FORMAT (16H MAX  CLASS ELEV7F8.0)
23 FORMAT (16H MAX  CLASS ELEV6F8.0)
24 FORMAT (16H MAX  CLASS ELEV5F8.0)
25 FORMAT (16H MAX  CLASS ELEV4F8.0)
26 FORMAT (16H MAX  CLASS ELEV3F8.0)
27 FORMAT (16H MAX  CLASS ELEV2F8.0)
28 FORMAT (16H MAX  CLASS ELEVF8.0)
29 FORMAT (16H MEAN CLASS ELEV7F8.0)
30 FORMAT (16H MEAN CLASS ELEV6F8.0)
31 FORMAT (16H MEAN CLASS ELEV5F8.0)
32 FORMAT (16H MEAN CLASS ELEV4F8.0)
33 FORMAT (16H MEAN CLASS ELEV3F8.0)
34 FORMAT (16H MEAN CLASS ELEV2F8.0)
35 FORMAT (16H MEAN CLASS ELEVF8.0)
36 FORMAT (16H PERCENT OF AREA7F8.2)
37 FORMAT (16H PERCENT OF AREA6F8.2)
38 FORMAT (16H PERCENT OF AREA5F8.2)
39 FORMAT (16H PERCENT OF AREA4F8.2)
40 FORMAT (16H PERCENT OF AREA3F8.2)
41 FORMAT (16H PERCENT OF AREA2F8.2)
42 FORMAT (16H PERCENT OF AREAF8.2)
43 FORMAT (I4)
44 FORMAT (3X,13H          NAME,F13.6,2X,F6.0,5X,I2)
45 FORMAT (15X,7F8.0)
46 FORMAT (6X,F6.0,5X,F12.5,5X,F7.2)
47 FORMAT(15HMISTAKE IN DATA)
48 FORMAT (43HNEXT DATA CARD MUST BE FORMAT 44,PUSH START)
   DIMENSION E(15),R(15),P(14),S(14),D(14),F(14)
   NOS=0
   J=1
   READ 43,NUM
   KACC=0
89 PAUSE
```

```
100 READ 44,AREA,EMAX,JAC
    KACC=KACC+1
    DO 90 J=1,15
 90  R(J)=0.
    J=1
    IF (JAC-14)50,50,114
 50 IF (JAC-7) 114,102,101
102 READ 45,E(1),E(2),E(3),E(4),E(5),E(6),E(7)
    READ 45,R(1),R(2),R(3),R(4),R(5),R(6),R(7)
 99 E(JAC+1)=EMAX
    RCON=R(JAC+1)
    IF (RCON)114,91,114
 91 RAEA=0.
    SUME=0.
    DO 103 J=1,JAC
103 RAEA=RAEA+R(J)
    DO 98 J=1,JAC
    P(J)=(R(J)/RAEA)
    D(J)=E(J+1)-E(J)
    F(J)=D(J)/2.+E(J)
    SUME=SUME+(F(J)*P(J))
    P(J)=P(J)*100.+.005
    IF (D(J))   114,114,98
 98 F(J)=F(J)+.5
    PUNCH 3
    PUNCH 3
    PUNCH 3
    PUNCH 1
    PUNCH 2
    PUNCH 3
    PUNCH 44,AREA,SUME,NOS
    PUNCH 3
    PUNCH 3
    PUNCH 5,E(1),E(2),E(3),E(4),E(5),E(6),E(7)
    PUNCH 6,E(2),E(3),E(4),E(5),E(6),E(7),E(8)
    PUNCH 7,F(1),F(2),F(3),F(4),F(5),F(6),F(7)
    PUNCH 9,P(1),P(2),P(3),P(4),P(5),P(6),P(7)
    PUNCH 3
    IF (JAC-7)114,111,93
111 PUNCH 3
    PUNCH 3
    PUNCH 10
    PUNCH 11
    PUNCH 3
    PUNCH 12
    PUNCH 13
    PUNCH 3
    NDEC=1
    SUME=E(1)
    SUMA=0.
    SUMP=0.
    J=1
    DO 112 J=1,JAC
    PK=(P(J)-.005)/10.
    DDK=D(J)/10.
```

```
      DS=AREA*PK/100.
      DO 112 NDEC=1,10
      SUME=SUME+DDK
      SUMA=SUMA+DS
      SUMP=SUMP+PK
  112 PUNCH 46,SUME,SUMA,SUMP
      IF (KACC-NUM)100,113,113
  101 READ 45,E(1),E(2),E(3),E(4),E(5),E(6),E(7)
      READ 45,R(1),R(2),R(3),R(4),R(5),R(6),R(7)
      READ 45,E(8),E(9),E(10),E(11),E(12),E(13),E(14)
      READ 45,R(8),R(9),R(10),R(11),R(12),R(13),R(14)
      GO TO 99
   93 PUNCH 3
      JA=JAC-7
      GO TO (104,105,106,107,108,109,110),JA
  104 PUNCH 21,E(8)
      PUNCH 28,E(9)
      PUNCH 35,F(8)
      PUNCH 42,P(8)
      GO TO 111
  105 PUNCH 20,E(8),E(9)
      PUNCH 27,E(9),E(10)
      PUNCH 34,F(8),F(9)
      PUNCH 41,P(8),P(9)
      GO TO 111
  106 PUNCH 19,E(8),E(9),E(10)
      PUNCH 26,E(9),E(10),E(11)
      PUNCH 33,F(8),F(9),F(10)
      PUNCH 40,P(8),P(9),P(10)
      GO TO 111
  107 PUNCH 18,E(8),E(9),E(10),E(11)
      PUNCH 25,E(9),E(10),E(11),E(12)
      PUNCH 32,F(8),F(9),F(10),F(11)
      PUNCH 39,P(8),P(9),P(10),P(11)
      GO TO 111
  108 PUNCH 17,E(8),E(9),E(10),E(11),E(12)
      PUNCH 24,E(9),E(10),E(11),E(12),E(13)
      PUNCH 31,F(8),F(9),F(10),F(11),F(12)
      PUNCH 38,P(8),P(9),P(10),P(11),P(12)
      GO TO 111
  109 PUNCH 16,E(8),E(9),E(10),E(11),E(12),E(13)
      PUNCH 23,E(9),E(10),E(11),E(12),E(13),E(14)
      PUNCH 30,F(8),F(9),F(10),F(11),F(12),F(13)
      PUNCH 37,P(8),P(9),P(10),P(11),P(12),P(13)
      GO TO 111
  110 PUNCH 15,E(8),E(9),E(10),E(11),E(12),E(13),E(14)
      PUNCH 22,E(9),E(10),E(11),E(12),E(13),E(14),E(15)
      PUNCH 29,F(8),F(9),F(10),F(11),F(12),F(13),F(14)
      PUNCH 36,P(8),P(9),P(10),P(11),P(12),P(13),P(14)
      GO TO 111
  114 TYPE 47
      TYPE 48
      GO TO 89
  113 STOP
      END
```